The biological potential of Mars and an application to potential MSL landing sites

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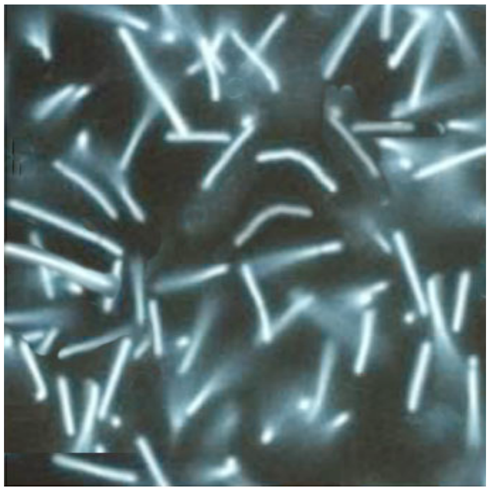
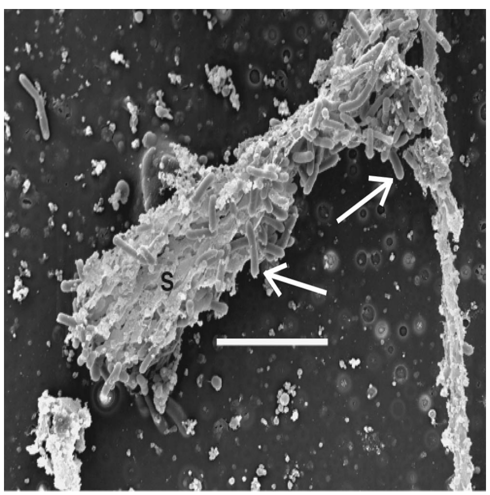
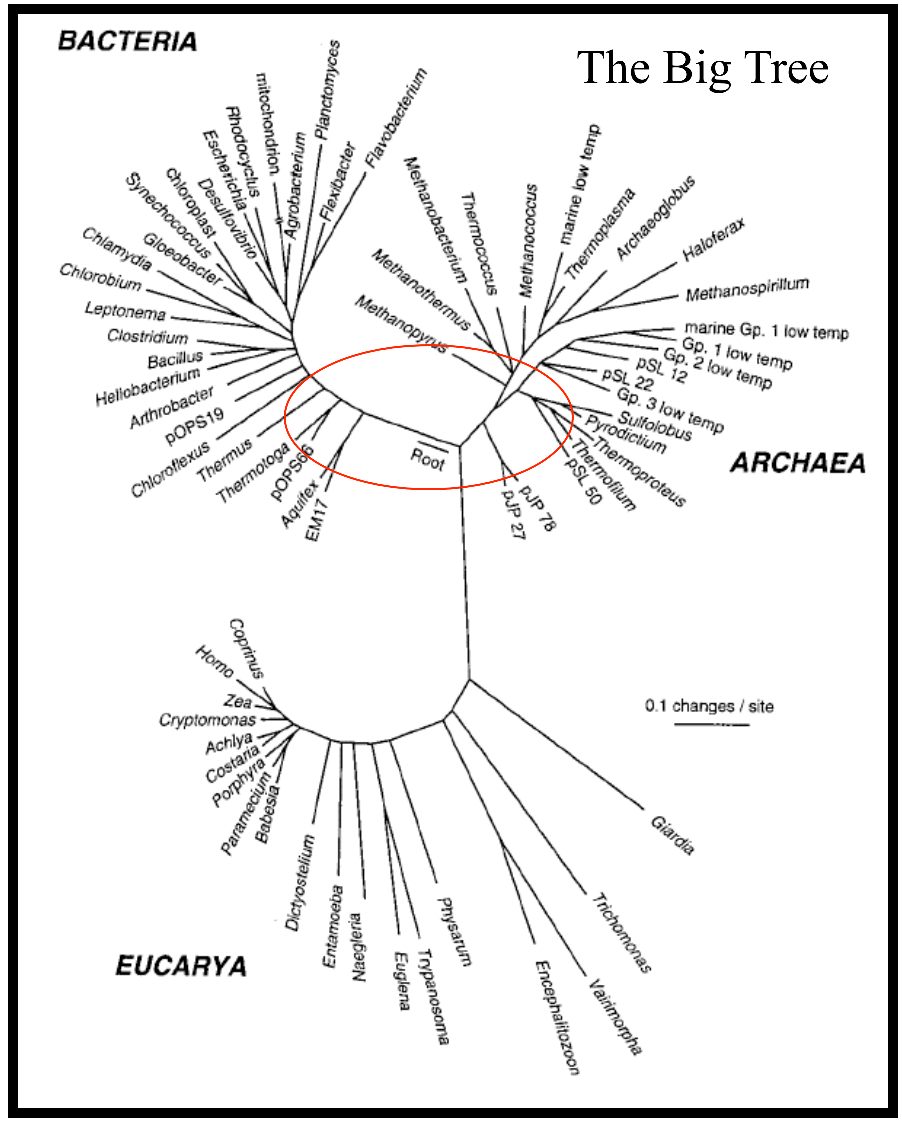
Follow the energy and the search for chemolithoautotrophs



Methanogens are typically found deep in the subsurface or in anoxic environments. Methanogens are responsible for the reduction of CO_2 by H_2 to produce CH_4



Scanning electron micrograph of rod-shaped bacterial cells (arrows) attached to sulfur crystals (S) in a sulfur-dominated hot spring, Scale bar 10 µm [Mathur et al., 2007]



Gibbs energy quantifies the energy available to support metabolism

$$\Delta G = \Delta G^\circ + RT(\ln Q)$$

Greater $-\Delta G$ value = more energy available
More available energy = more amount of biomass

Autotrophic **aerobes** require 80-170 kJ to produce 1 gram dry weight of biomass

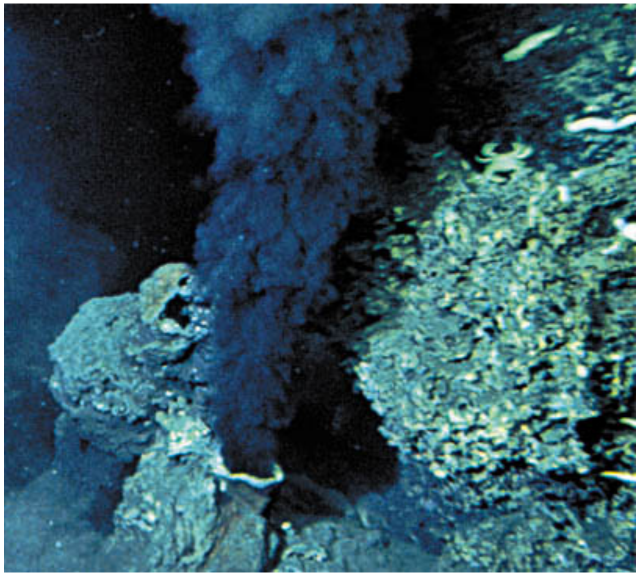
Autotrophic **anaerobes** require 30-40 kJ/g biomass
[Heijnen and van Dijken, 1992]

Different geological environments provide different amounts of energy

Grand Prismatic Spring in Yellowstone National Park

Columbia River Basalt

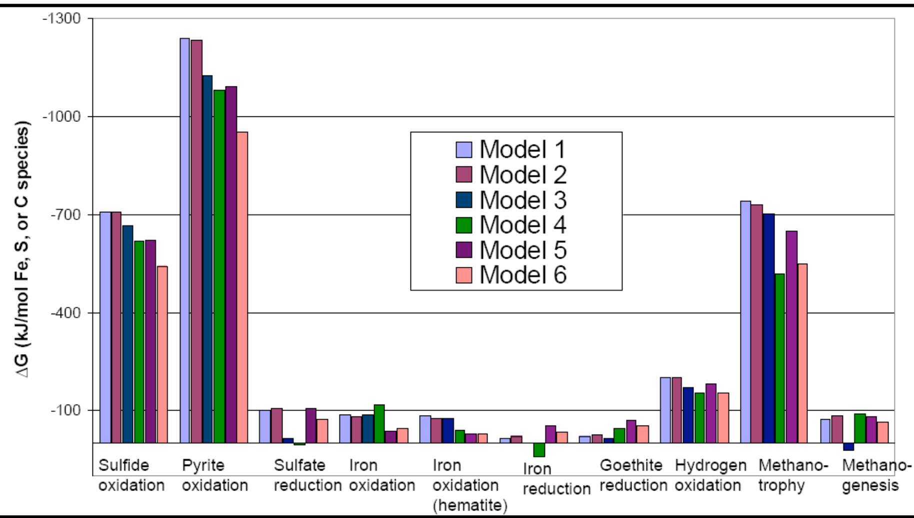
Hydrothermal system



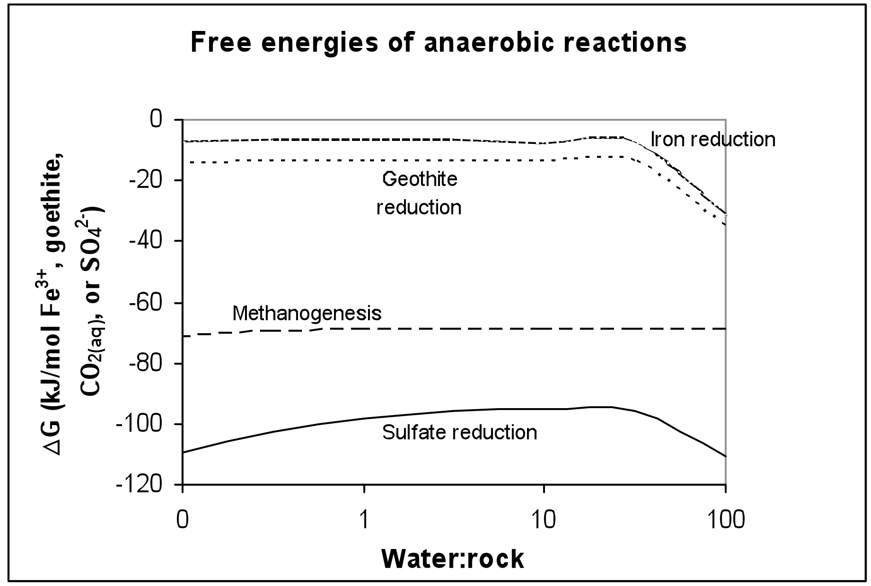
Used geochemical modeling to constrain the geochemistry of the environment

Table 1: Chemolithoautotrophic reactions considered in this study that may have provided energy sources to potential martian organisms.

Rxn #	Involving mainly aqueous species	
1	$H_2S + 2\ O_{2(aq)} = SO_4^{2-} + 2\ H^+$	(Sulfide oxidation)
2	$Pyrite + H_2O + 3.5\ O_{2(aq)} = Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+$	(Pyrite oxidation)
3	$SO_4^{2-} + 2\ H^+ + 4\ H_{2(aq)} = H_2S + 4\ H_2O$	(Sulfate reduction)
4	$Fe^{2+}\ 0.25\ O_{2(aq)} + H^+ = Fe^{3+} + 0.5\ H_2O$	(Iron oxidation)
5	$Fe^{2+} + H_2O + 0.25\ O_{2(aq)} = 0.5\ Hematite + 2\ H^+$	(Iron oxidation-precip)
6	$Fe^{3+} + 0.5\ H_{2(aq)} = Fe^{2+} + H^+$	(Iron reduction)
7	$Goethite + 2\ H^+ + 0.5\ H_{2(aq)} = 2\ H_2O + Fe^{2+}$	(Goethite reduction)
8	$H_{2(aq)} + 0.5\ O_{2(aq)} = H_2O$	(Hydrogen oxidation)
9	$CH_{4(aq)} + 2\ O_{2(aq)} = 2\ H_2O + CO_{2(aq)}$	(Methanotrophy)
10	$CO_{2(aq)} + 4\ H_{2(aq)} = 2\ H_2O + CH_{4(aq)}$	(Methanogenesis)



Energy available from reactions in martian basalt aquifers

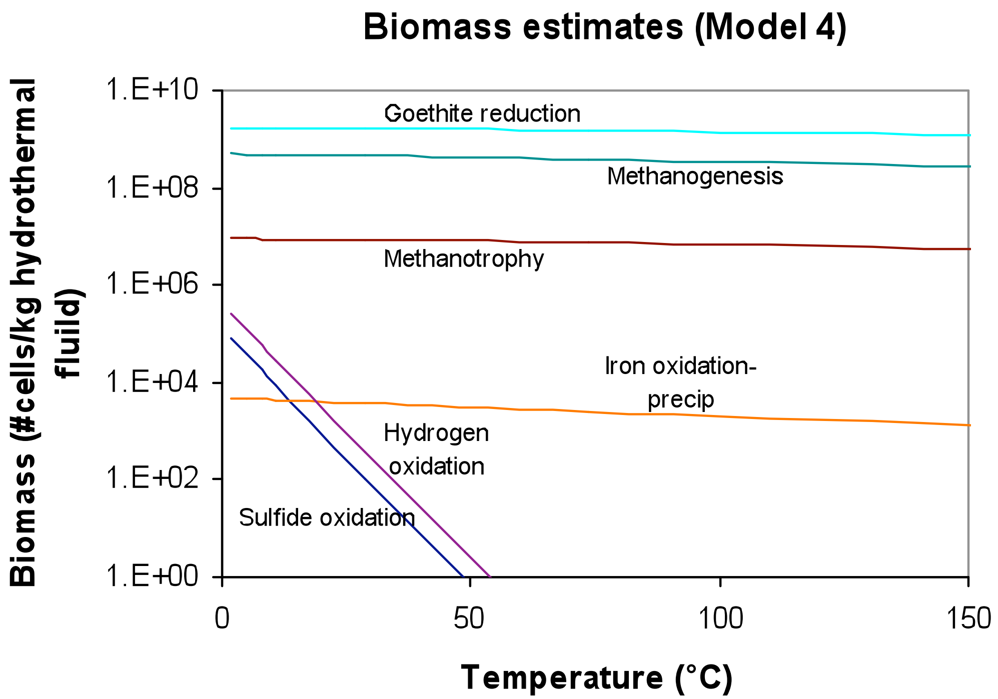


- Nine out of ten chemolithotrophic reactions are thermodynamically favorable even though anaerobic reactions should dominate in this type of environment

- Methanogenesis and sulfate reduction could produce up to 10^8cells/cm^3

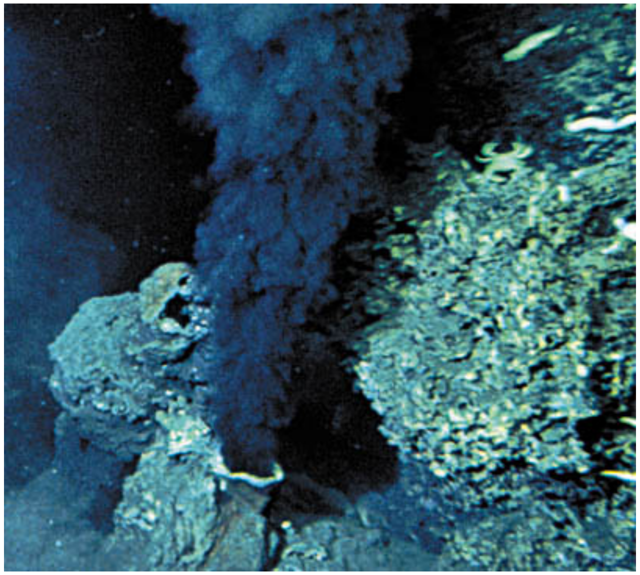
- This is on the high end of what is found in terrestrial subsurface environments (10^4-10^8 cells/cm^3 have been detected)

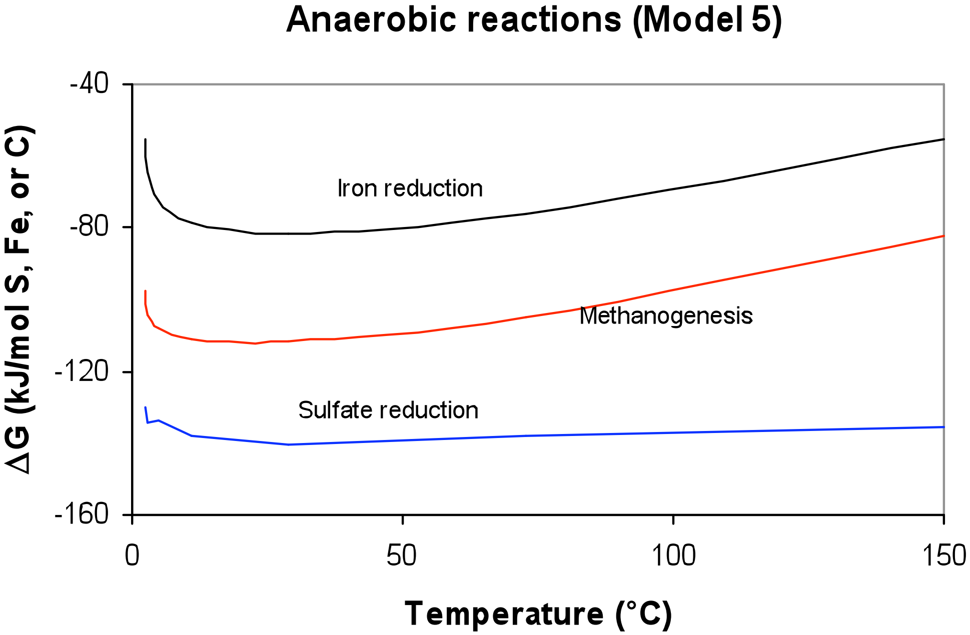
Energy available from reactions in putative martian hot spring



- Equates to 10^1-10^5cells/mL, which compares to terrestrial values of 10^6 cells/cm^3
- Assuming a martian hydrothermal fluid flux of 3×10^{11} kg/yr, we calculated that this system could have supported 6×10^7g biomass/yr

Energy available from mixing martian hydrothermal fluids with groundwaters





- Sulfate reduction could have produced up to 8.4 x 10^5 cells/mL hydrothermal fluid. Deep-sea hydrothermal vents can support up to 10^9 cells/mL
- Methanogenesis would have produced 6.7 x 10^5 cells/ mL hydrothermal fluid compared to a reported value of 5 x 10^7 cells/mL fluid for a modeled terrestrial hydrothermal system *[McCollom and Shock, 1997]*
- Using fluid fluxes of 5 x 10^5 kg/hr *[Converse, 1984]*, 249 grams of biomass could be produced per hour at one martian hydrothermal system

MSL potential landing site application

- Which of our models are applicable to the different landing sites?
- Do we have enough mineralogy data to determine oxidation states of landing site?
- Was there any redox disequilibrium at the potential sites?
- Would potential chemolithotrophs have been able to take advantage of redox reactions?

Summary table for MER sites

NAME	TARGET	RATIONALE	PRIORITY
Gusev Crater	Possible crater lake, layering, deltas, silica, Fe-sulfates	Possible fumarolic and hydrothermal deposit [Yen et al., 2008] similar to an environment like Yellowstone. Our results imply that chemolithoautotrophic reactions such as ferric iron reduction and methanogenesis could have been the most favorable reactions. A maximum of ~2 x 10^6 cells/ml hydrothermal fluid could have potentially been produced	Medium
Meridiani Planum	Hematite concretions, low-T acid environment, ferric Fe, sulfates, oxidizing, acidic groundwater	Evidence that the rocks have been exposed to surface water at shallow depths [Squyres et al., 2004], suggesting a substantial degree of low-temperature chemical alteration. Our results imply that if Meridiani Planum was a location where low-temperature, shallow water altered basalt, then ~10^8 cells/cm^3 basalt could have been produced	High

Summary table for each landing site

NAME	TARGET	RATIONALE	PRIORITY
Holden Crater	Fluvial layers, phyllosilicates	No evidence for any redox chemistry or chemical disequilibrium having occurred that would have been able to support chemolithotrophs	Low
Eberswalde Crater	Delta, phyllosilicates	Clays show that water was present, but no redox chemistry is involved, therefore not biologically useful from a thermodynamic point of view	Low
Mawrth Vallis	Layered phyllosilicates, oxidized and reduced Fe, hydrothermal?	Reduced and oxidized iron (nontronite) has been detected. Nontronite can form from the weathering of basalt at low temperatures or precipitate from hydrothermal fluids	High
Gale Crater	Layered sulfates, phyllosilicates, Fe-smectite	Evidence for both oxidizing and reducing conditions in the form of reduced smectite and oxidized sulfates	Medium

Conclusions

- Sites with lacustrine settings or fluvial channels would not harbor enough geochemical energy to support chemosynthesis
- Sites with evidence of hydrothermal alteration and interesting redox chemistry would have had more biological potential based on thermodynamic energy requirements
- Gale Crater and Mawrth Vallis may have had more biological potential if chemolithotrophic reactions are considered